Benthos

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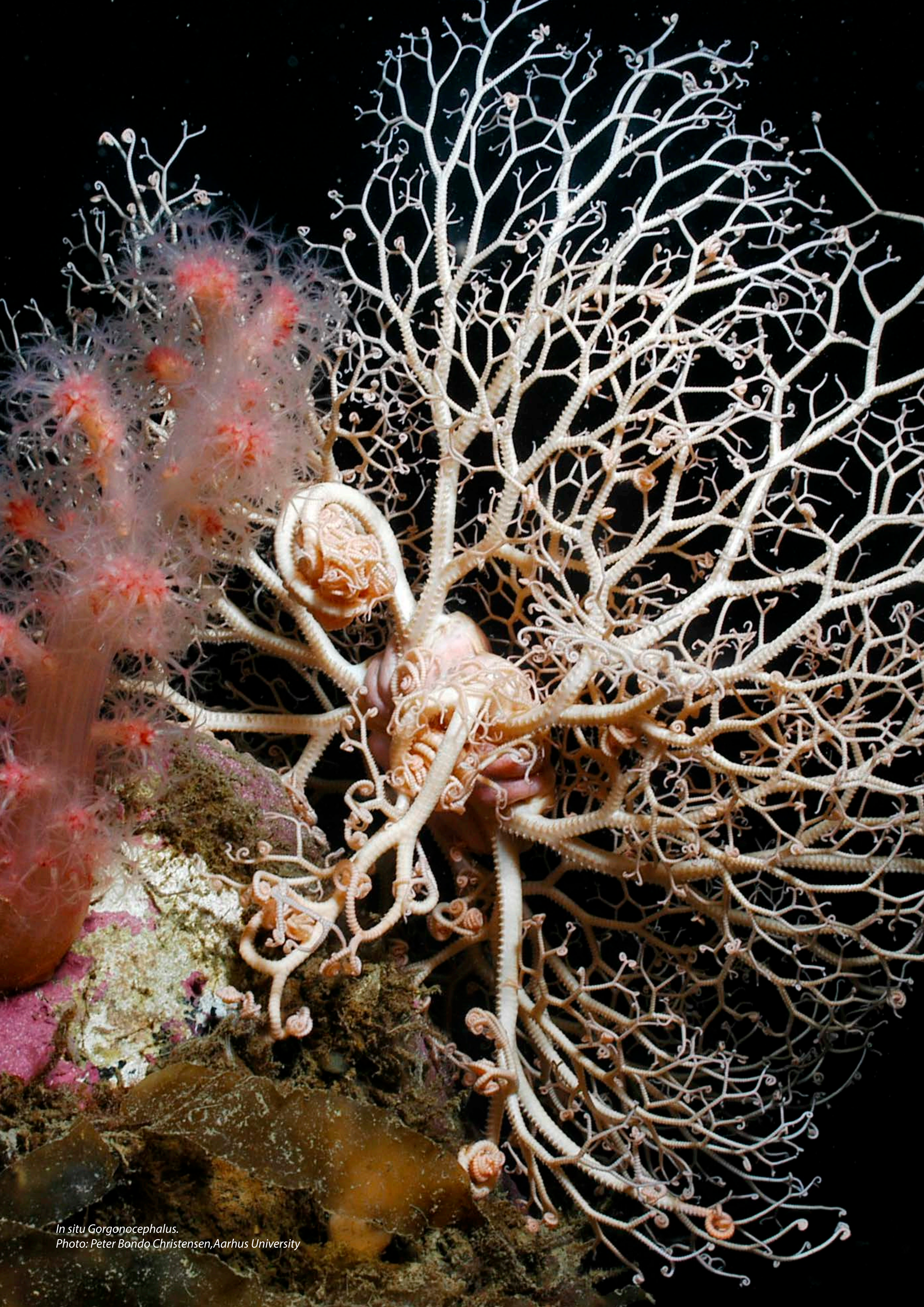
Published in:
State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna International Secretariat, 978-9935-431-63-9

Publication date:
2017

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Jørgensen, L. L., Archambault, P., Blicher, M., Denisenko, N., Gudmundsson, G., Iken, K., Roy, V., Sørensen, J., Anisimova, N., Behe, C., Bluhm, B. A., Denisenko, S., Metcalf, V., Olafsdóttir, S., Schiøtte, T., Tendal, O. S., Ravelo, A. M., Kdra, M., & Piepenburg, D. (2017). Benthos. In T. Barry, C. Price, M. Olsen, T. Christensen, & M. Frederiksen (Eds.), *State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna International Secretariat, 978-9935-431-63-9* (pp. 85-107). http://www.arcticbiodiversity.is/marine



In situ Gorgonocephalus.
Photo: Peter Bondo Christensen,Aarhus University

3.3 Benthos

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Snapshot

- Currently, > 4,000 Arctic macro- and megabenthic species are known, representing the majority of Arctic marine faunal diversity. This estimate is expected to increase.
- Benthic invertebrates are food to fishes, marine mammals, seabirds and humans, and are commercially harvested.
- Traditional Knowledge (TK) emphasizes the link between the benthic species and their predators, such as walrus, and their significance to culture.
- Decadal changes in benthos biodiversity are observed in some well-studied regions, such as the Barents Sea and Chukchi Sea.
- Drivers related to climate-change such as warming, ice decline and acidification are affecting the benthic community on a pan-Arctic scale, while drivers such as trawling, river/glacier discharge and invasive species have significant impact on regional or local scales.
- Increasing numbers of species are moving into, or shifting, their distributions in Arctic waters. These species will outcompete, prey on or offer less nutritious value as prey for Arctic species.
- Current monitoring efforts have focused on macro- and megabenthic species, but have been confined to the Chukchi Sea and the Barents Sea. Efforts are increasing in waters of Greenland, Iceland, the Canadian Arctic, and in the Norwegian Sea. All other Arctic Marine Areas are lacking long-term benthic monitoring.
- As a first step towards an international collaborative monitoring framework, we recommend to develop a time- and cost-effective, long-term and standardized monitoring of megabenthic communities in all Arctic regions with regular annual groundfish assessment surveys. Expanding monitoring on micro-, meio- and macrobenthic groups is encouraged.

3.3.1 Introduction

The seabed environment includes a great variety of physically diverse and biologically distinct habitats that, collectively, add to regional biodiversity of benthic fauna. Large spatial and temporal variation in community structure of benthic fauna is related to water depth (from shallow intertidal zones to the deep abyss), currents, temperature, food availability, irradiance, and type of substratum, ranging from hard and rocky, to soft, muddy floors (e.g., Gray 2002, Piepenburg 2005). Sea ice is an additional environmental driver that influences benthos, because it modifies hydrographic features, scours in shallow water, and affects primary production, amongst other effects (Sejr et al. 2009). Arctic benthic fauna act as long-term integrators of overlying water-column processes because of life spans on the order of years or decades (e.g., Sejr et al. 2002, Blicher et al. 2007). Although some benthic organisms are mobile, many remain relatively stationary on or in bottom sediments and their community patterns are thus directly affected by local hydrographic conditions and the export production regime from the overlying water column (Roy et al. 2014). Consequently, the distribution, abundance and biomass of benthic invertebrate species vary on multiple spatial scales. Benthic organisms are key components of remineralization processes (Blicher et al. 2009, Link et al. 2013 a, b) and also provide an important food source to higher trophic levels, such as many fishes, seabirds and marine mammals (Stirling 1997, Born et al. 2003, Bluhm and Gradinger 2008, Blicher et al. 2011). Despite their importance in Arctic food webs and other functional roles in the ecosystem, relatively little is known about diversity of some taxonomic groups and regions, distributional patterns, and the environmental factors that may drive benthic invertebrate community patterns across larger spatial extents, especially on a pan-Arctic scale.

Benthic invertebrates live within the sediment (infauna) or are either attached or move along the seafloor (epifauna) or inhabit the water column just above the bottom (supra- or hyperbenthos). Benthic invertebrates are typically divided into size categories: organisms that can be identified from seafloor photographs or are caught by trawls (megafauna); organisms > 1.0 mm (macrofauna); organisms that are 0.1–1.0 mm (meiofauna); or organisms < 0.1 mm (microfauna). Members of all these groups comprise the full diversity of benthic communities. A wide range of different types of specialized sampling gears, including trawls, corers, grabs, remotely operated vehicles (ROV), and scuba diving, are needed to sample all faunal components and/or a given habitat appropriately (see Eleftheriou 2013).

Standardization across gears is rather challenging, as slight differences in even the same gear types can cause differences in catch efficiencies. It also is often not possible to apply the full suite of different sampling gear types at a given location to gather a complete range of benthic organisms. For these reasons, the compilation presented here includes only the subtidal mega- and macrofauna, for which the most complete data are available on the pan-Arctic scale. However, meio- and microfauna are also discussed in the Arctic Basin section of this chapter. The exclusion of the smaller-sized benthic components (meio- and microfauna, but see "Arctic Basins") greatly underestimates the actual number of benthic invertebrate species in the Arctic Ocean, but this provides the most practical approach at this time due to the feasibility, capacity and logistical focus of many biodiversity studies on epibenthic fauna for monitoring purposes.

This chapter has two major purposes; first to utilize existing benthic biodiversity information (from grab, box core, benthic trawl, dredge and sledge methods) to map biodiversity (Box 3.3.1), status and trends (Fig. 3.3.4-3.3.6). Second, to use megafaunal data from bottom trawls to establish a current reference state (Box 3.3.2) against which future changes (Fig. 3.3.2) can be compared for eight Arctic Marine Areas (AMAs) defined by the Circumpolar Biodiversity Monitoring Program (CBMP). Currently, data collected via annual fish assessment surveys are the most comprehensive data sets (spatially and temporally); therefore, monitoring recommendations on a Pan-Arctic scale are restricted to such megafaunal data. The CBMP Benthos Expert Network recommends to develop a collaborative, cost-effective, long-term and standardized monitoring of megabenthic communities in all Arctic regions with regular annual groundfish assessment surveys.

3.3.2 Current monitoring

Present state of knowledge – species richness and sampling effort

Benthic investigations in the Arctic started centuries ago and include the British expeditions of the *Lightning* and *Porcupine* (1860-1880), the Norwegian *Michael Sars* expeditions, and the early Danish expeditions of the *Ingolf* (1895-1896), *Thor* (1903) and *Dana* (1920-22). Together, these early investigations provided considerable taxonomic knowledge of Arctic benthic invertebrate fauna. Initially the primary goal was to register new species, but since the 1920s the quantification of biomass, abundance, and species richness became more important (Zenkevich 1963). Recent estimates of total species richness in the Arctic suggest that benthic invertebrates comprise >4000 species (CAFF 2010).

To date, the most studied areas are the Chukchi Sea and the Barents Sea, while information about fauna in other areas such as the Canadian Arctic Shelf and the Greenland region was limited until recently, and is still sparse for some groups including the central Arctic, Faroes Archipelago and Iceland (Box 3.3.1 and 3.3.2). A lack of consistency and methodological standardization has been recognized as a major obstacle to assess large-scale (from regional to pan-Arctic) and long-term dynamics in benthic communities (Bluhm et al. 2011, Piepenburg et al. 2011, Weslawski et al. 2011), although it is generally accepted that this information is urgently needed to assess effects of anthropogenic activities and a changing environment. To foster pan-Arctic comparisons of benthic species assemblages, the CBMP Benthos Expert Network presents historical baselines per region and describes current sampling activities, which are cornerstones towards establishing a coordinated pan-Arctic long-term monitoring plan.


Small amphipod with Chaetognath.
Photo: Liz Lindal Jørgensen


Megafauna bottom trawl results from the Chukchi Sea shelf near the Canada Basin including sea stars, brittle stars, clams, some snails and crabs.
Photo: Bodil Bluhm, University of Alaska Fairbanks

A

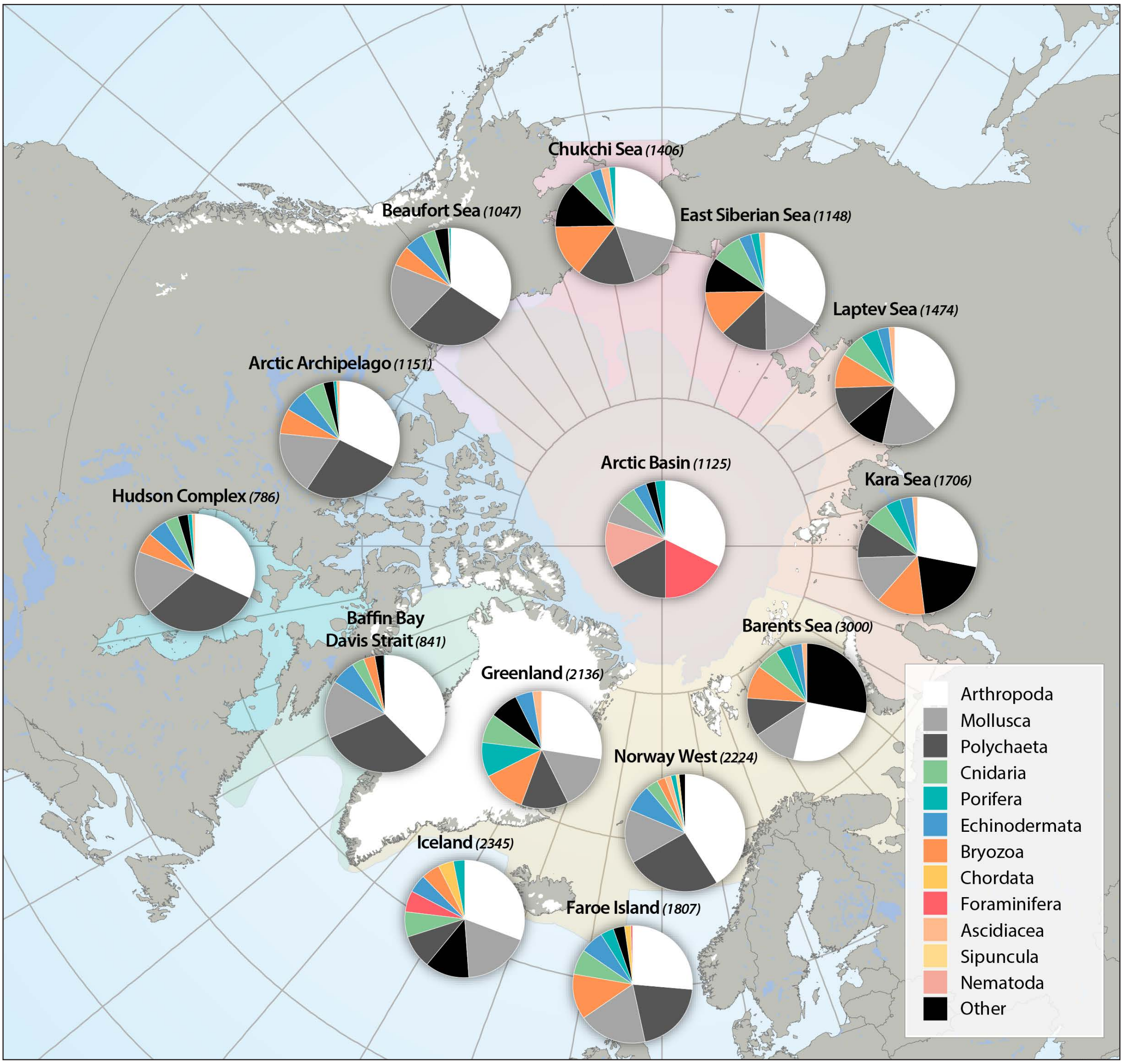
B

Figure 3.3.1. The Arctic Basin where suggested future long-term monitoring of trawl-megafauna should capture possible changes along the flow of the Arctic Circumpolar Boundary Current (Figure A, blue line) and the Arctic deep-water exchange (Figure b, green line). Adapted from Bluhm et al. (2015).

Box 3.3.1: Benthic macro- and megafauna

Distribution of major benthic invertebrate groups in the Arctic

Arthropods (e.g., shrimps, crabs, sea spiders, amphipods, isopods) dominate taxon numbers in all Arctic regions, followed by polychaetes (e.g., bristle worms) and mollusks (e.g., gastropods, bivalves). Other taxon groups are diverse in some regions, such as bryozoans in the Kara Sea, cnidarians in the Atlantic Arctic, and foraminiferans in the Arctic deep-sea basins. This pattern is biased, however, by the meiofauna inclusion for the Arctic Basin (macro- and meiofauna size ranges overlap substantially in deep-sea fauna, so nematodes and foraminiferans are included) and the influence of a lack of specialists for some difficult taxonomic groups.



Box figure 3.3.1 Regional pie charts showing the species/taxon number (in brackets) per region and the relative proportion of certain taxa in species richness. Regions have been sampled with one or several types of sampling gears, including different grabs, sledges and trawls, but also subjected to different levels of taxonomic resolution for the different taxon groups. Data from: Icelandic Institute of Natural History, Iceland; Marine Research Institute, Iceland; Faroese Museum of Natural History, Faroe Islands; University of Alaska Fairbanks, U.S.; Natural History Museum of Denmark, Denmark; Zoological Institute of the Russian Academy of Sciences, Russia; Université du Québec à Rimouski, Canada; Canadian Museum of Nature, Canada; Fisheries and Oceans Canada; and Institute of Marine Research, Norway. For the Arctic Basin, data sources are listed in Bluhm et al. (2011).

Eastern Atlantic Arctic (incl. Barents Sea, the Faroe Islands, Iceland, but excluding eastern Greenland)

Barents Sea and Norwegian Sea

Historical benthos sampling

Between the end of the 19th Century and 2004, about 3000 stations had been sampled in the Barents Sea at depths from the tidal zone to 1,200 m, using a variety of different grabs, trawls, and dredges (Denisenko 2013). The latest report lists 2,435 macro- and megafaunal species for the Barents Sea (Sirenko 2001), but this figure does not include the species/taxa inhabiting the west of the Nord Cape nor new records collected in the recent two decades. Predictive models suggest that the 'true' species richness may be up to 3,200 taxa (Denisenko 2013).

In Norway, the program MAREANO, running from 2006 to 2017 (ongoing), created a baseline understanding of biotopes and habitats along the western shelf of northern Norway and in the southern Barents Sea. From 2 m beam-trawl, an epibenthic sampling sledge and Van Veen grab samples, a total of 2,225 epi-, in- and hyperbenthic macro and megafauna species/taxa have been recorded. This type of multi-equipment approach showed that Arthropoda, Annelida and Mollusca are the most speciose taxa (Box 3.3.1).

Current benthic megafauna monitoring by trawl

Since 2005, a Long-Term Monitoring for Benthic Megafauna program has been part of the annual ground fish surveys conducted in the framework of the Joint Annual Norwegian-Russian Ecosystem Survey in the Barents Sea (Anisimova et al. 2010, 2011, IMR Norway 2015, Jørgensen et al. 2015, 2016), where two benthic taxonomic experts identify megabenthic organisms in the bottom-trawl catches to the lowest practical taxonomic level on every cruise, and assess megabenthic abundance and biomass of each taxon. In the Long-Term Monitoring for Benthic Megafauna approach, selected specimens are photographed and voucher specimens were preserved for taxonomic reference purposes. Benthic bycatch information is used to assess distribution patterns of megabenthic communities and their changes over space and time in relation to potential drivers. This program has recorded a total of 380 species/taxa for the Barents Sea through increasing taxonomic knowledge, a Russian-Norwegian taxonomic exchange program and taxonomic standardization to international databases of accepted names (e.g., World Register of Marine Species, Ocean Biogeographic Information System). Species/taxon richness per station in 2011 varied from 2 to 72, with lowest values in the southeastern Barents Sea and highest in the central Barents Sea (Box 3.3.2). Out of 241 2-m-beam-trawl hauls along the western coast of Norway, MAREANO recorded more than 100 species/taxa at 32 stations, with a maximum number of 330 species/taxa (Box 3.3.2).

Multiple approaches to deep sea monitoring

The Long-term Ecological Research (LTER) Observatory HAUSGARTEN in the eastern Fram Strait is an array of stations at depths of 1,200-5,600 m. It has been photographically sampled regularly since 2000 in the framework of a long-term scientific program of the German Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (Bergmann et al. 2011). In the photographic time series, a total of 27 megabenthic taxa have been identified, but around 50 megabenthic species have been recorded when adding supporting trawl material (Bergmann et al. 2011). While the sampling method (seabed imaging) is not the same as that regularly applied in the other regions (trawl surveys), it is strongly advised that the HAUSGARTEN location will be integrated in the CBMP, as it represents the only existing Arctic deep-sea benthic observatory.

The Faroe Islands

Historical benthos sampling

The BIOFAR project (1988 to 1990) conducted benthic investigations at about 600 stations at depths from 20 to 2,420 m, with grabs, trawls, sledges and dredges, especially in the deeper parts of the Faroese Economic Exclusive Zone (EEZ). Although not complete, the Natural History Museum of the Faroe Islands today holds records of about 1807 mega- and macrofaunal species/taxa from this region (Box 3.3.1).

Current benthic megafauna monitoring by trawl

The annual trawl surveys on the Faroe Shelf and Faroe Bank are monitoring 100 stations in early spring, and 200 stations in August. Although only fish data have been recorded to date, the Fisheries Research Institute aims to begin to also include benthic invertebrate bycatch as part of the annual surveys by 2019. Benthic monitoring will be conducted in much the same way as in Norway (see the Long-Term Monitoring for Benthic Megafauna program, above), Iceland and Greenland (see below), where experts in marine megabenthic taxonomy will participate in ground fish survey cruises and identify invertebrate bycatch to the lowest taxonomic level and register the abundance and biomass of each taxon.

Iceland

Historical benthos sampling

The main objective of the ongoing BIOICE project is to revise a taxonomic inventory of the marine invertebrates found in the waters of the Icelandic EEZ and to update knowledge on their geographic distribution in this region (Box 3.3.1). Sampling was completed during 1991-2004 and included the biogeographic boundary between boreal and Arctic regions of the North Atlantic, comprising 579 stations at depths between 20 and 3,100 m, at various bottom types with water temperatures ranging from -1°C to over 9°C. In the course of the project, over 2,345 benthic species/taxa, have been registered so far with voucher specimens in museum collections.

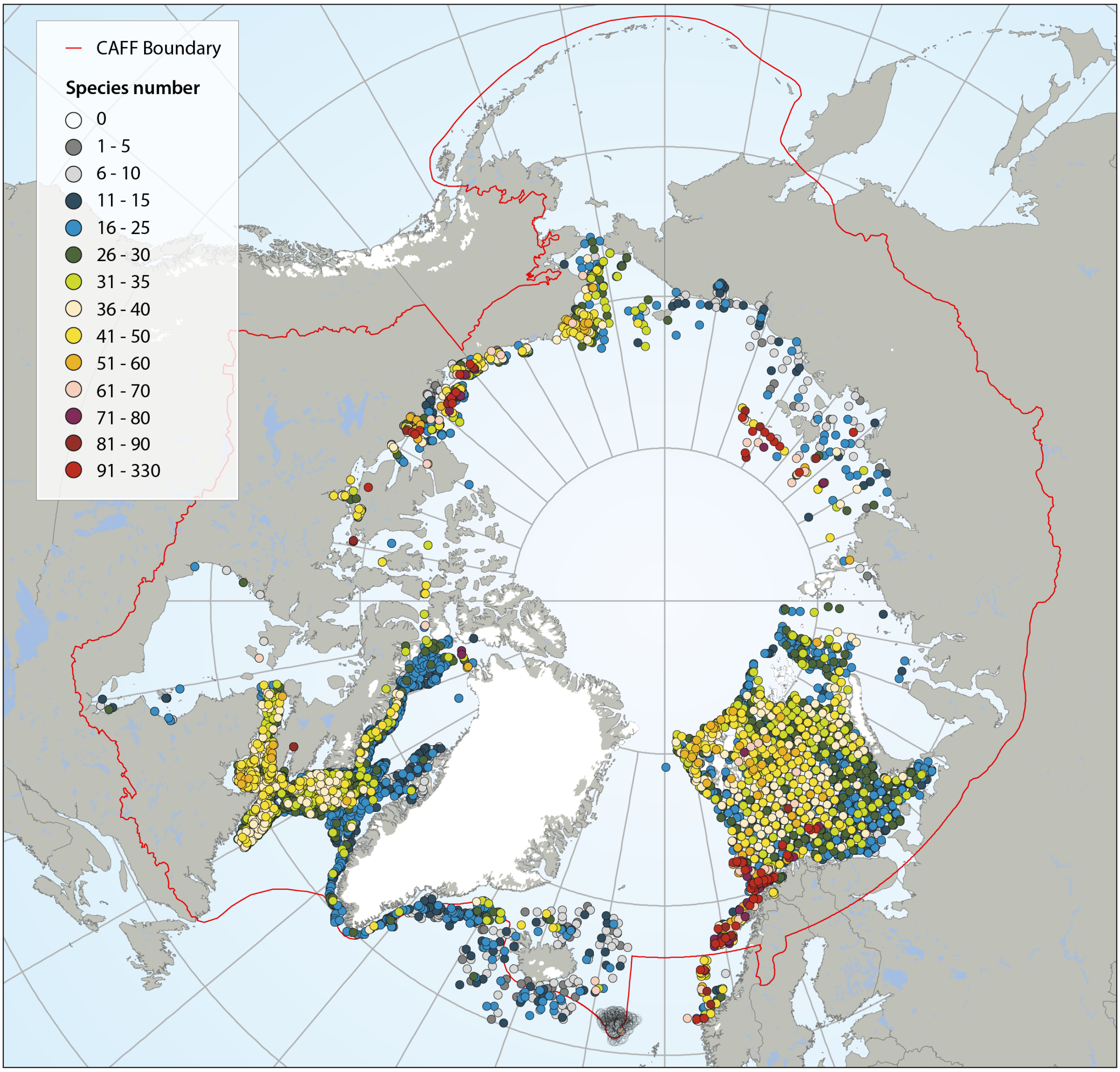
Current benthic megafauna monitoring by trawl

In line with the Russian-Norwegian Long-Term Monitoring for Benthic Megafauna approach, the Marine Research Institute (MRI) of Iceland implemented a three-year pilot project in 2015 in order to make the identification of all benthic invertebrate bycatch an integral part of the annual Icelandic Autumn Groundfish Survey. This pilot program is also related to the Greenlandic three-year pilot study (see below) to standardize methodologies, including taxonomic identifications of megabenthos, across the Atlantic Arctic. The survey includes approximately 400 fixed stations within

Box 3.3.2: Benthic megafauna

Pan-Arctic taxon richness in trawl benthos

More than 100 megafaunal species/taxa have been recorded at trawl stations (red) in the eastern Beaufort Sea, the deeper parts of the Laptev Sea, and the west coast of Norway. The lowest numbers (blue/grey) have been recorded in around Greenland and Iceland, in the southeastern Barents Sea and southern Chukchi Sea, as well as the shallower parts of the Kara, East Siberian, and Laptev Seas. Intermediate species/taxon richness (yellow) have been recorded in the Baffin Bay-Davis Strait/Hudson Complex, the central and northern Barents Sea, the western Beaufort Sea, the northeastern Chukchi Sea, and the Canadian Archipelago.



Box figure 3.3.2 Number of megafauna species/taxa in the Arctic (7,322 stations in total), based on recent trawl investigations. Stations with highest species/taxon number are sorted to the top, meaning that dense concentrations of stations (e.g. Eastern Canada, Barents Sea), with low species numbers are hidden behind stations with higher species numbers. Also note that species numbers are somewhat biased by differing taxonomic resolution between studies. Data from: Icelandic Institute of Natural History, Iceland; Marine Research Institute, Iceland; University of Alaska, Fairbanks, U.S.; Greenland Institute of Natural Resources, Greenland; Zoological Institute of the Russian Academy of Sciences, St. Petersburg, Russia; Université du Québec à Rimouski, Canada; Fisheries and Oceans Canada; Institute of Marine Research, Norway; and Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia.

the Icelandic EEZ, encompassing sites at the continental shelf and slope to 1,500 m depth. The research area is divided into a shallow-water area (0-400 m) and a deep-water area (> 400-1,500 m), but currently benthic megafauna bycatch is only analyzed for the deep-water area. Photos of voucher species will be included in a benthos identification catalogue of Icelandic waters and will be part of an overarching catalogue of the benthic fauna of the greater Arctic area. Data are stored in a relational database (Oracle) jointly run by the MRI and the Icelandic Institute of Natural History. Preliminary findings for the first cruise in 2015 showed that the cold-water habitats (<0°C) north and east of Iceland comprise on the average less than 15 species/taxa per haul, whereas over 19 species/taxa per haul occurred in more temperate waters (>0°C) south and west of Iceland. The total number of megabenthos species/taxa found in both regions is 160 (Box 3.3.2).

Greenland (west and east coasts)

Historical benthos sampling

The compilation of species/taxon richness and distribution across phyla for Greenland waters (Box 3.3.1) is based on all available faunistic information from more than 500 sources from the late 1700s until 2003, providing information about Greenlandic marine benthos down to 1,000 m depth (Tendal and Schiøtte 2003). The complete data set encompasses more than 2,100 species of benthic invertebrates, with arthropods, mollusks and polychaetes representing 55% of the species/taxa. However, these figures are strongly affected by sampling effort. The number of species/taxa registered in each of 18 sub-regions is significantly correlated with number of sampling stations. Still, this extensive data compilation is an extremely valuable baseline for current and future benthic studies in Greenland waters.

Current monitoring of megafauna by trawl

In a three-year pilot study, (Initiating North Atlantic Benthos Monitoring, INAMon) starting in 2015, the Long-Term Monitoring for Benthic Megafauna approach of bycatch surveys (see above) was adopted for Greenland waters, with the participation of benthos experts from all Atlantic Arctic countries. Benthic bycatch data are being collected during annual shrimp/fish assessment trawl surveys at more than 400 trawl stations. The goal is to make the documentation of benthos bycatch an integrated part of the standard protocol on the six annual shrimp/fish trawl surveys of the Greenland Institute of Natural Resources in the waters off west and southeast Greenland. INAMon works as a platform for international knowledge-exchange aiming to ensure standardized methodology, including taxonomic identification, across regions to assist in regional comparisons of future monitoring data. More than 400 megafauna species/taxa were registered in 2015. The average number of species/taxa per trawl station was 14 for the entire survey area, with a range from 1 to 44 (Box 3.3.2). The shrimp/fish trawl surveys in Greenland currently cover only areas of current or previous commercial trawling. Therefore, the results will inevitably be biased towards more trawling-impacted habitats, since un-trawled areas that may sustain a more diverse fauna are poorly represented in the data set. Preliminary data suggest that shallow offshore banks may represent oases with high benthic biomass and species richness. There are currently no shrimp/fish surveys in the northernmost part of Greenland, and the monitoring of benthos will continue to rely on occasional project-based research surveys.

Kara and Laptev Seas

Historical benthos sampling

Despite a long history of biological studies, knowledge of benthic species diversity in the Kara and Laptev Seas remains incomplete. A compilation of benthic species numbers from a variety of historic sampling campaigns (Sirenko 2001, 2003) created an important baseline, including a total of 2,489 macro- and megabenthic species/taxa, with arthropods, mollusks, bryozoans and polychaetes being the most diverse groups (Box 3.3.1). Benthic species richness in this Arctic region decreases toward the east, very likely due to a decreasing influence of the Atlantic water inflow. In the Kara Sea, species richness can be 20 to 25% higher for many benthic groups than in the Laptev Sea (Piepenburg et al. 2011, Denisenko and Grebmeier 2015).

Benthic megafauna monitoring by trawl

No regular bottom trawl surveys are currently conducted in the Laptev and Kara Seas. The Zoological Institute of the Russian Academy of Sciences carried out the most comprehensive, recent bottom trawling sampling in the Laptev Sea in 1993 to 1995. Species/taxon numbers in the trawl catches varied from 1 to 64 (mean: 16; unpublished data). The trawl samples collected in the Kara Sea (1931 to 1938) have not yet been fully processed. In total, more than 150 species (Gorbunov, 1946) have been found (Box 3.3.2). It is essential to continue benthic investigations in both Arctic seas to gauge the effects of declining sea-ice cover and the potential effects of an expected increase in ship traffic.

Pacific Arctic (incl. East Siberian Sea, Chukchi Sea, northern Bering Sea)

East Siberian Sea

Historical benthos sampling

The East Siberian Sea is characterized by the lowest known macrobenthic species richness among all Eurasian Arctic seas (a total of 1,148 species; Sirenko 2010). Similar to other Eurasian Arctic seas, the most diverse groups are arthropods, mollusks, and polychaetes (Box 3.3.1). The Zoological Institute of the Russian Academy of Sciences conducted the most intensive benthos sampling using bottom trawls in 1930s and at the beginning of the 2000s, although the latter was restricted to the inner shelf. According to current knowledge, the East Siberian Sea bottom fauna has highest species/taxon richness at the northwestern border to the Laptev Sea and at the southeastern border to the Chukchi Sea.

Historical benthic megafauna monitoring by trawl

No current trawl surveys are being conducted in the East Siberian Sea. Species number from historical trawl samples established from collections in 2004 vary from 1 to 28 (mean of 8) per station, which is considerably lower than in the Laptev Sea, despite the expected higher diversity based on the transitional Pacific Arctic characterization of the East Siberian Sea neighboring the Chukchi Sea (Box 3.3.2). This pattern in the Laptev Sea may be partly due to differences in gear and sampling effort. Benthic diversity is expected to be higher in the deeper part under ice cover. In the northwestern East Siberian Sea, the local benthic diversity has been recorded with 110-120 species (Gorbunov 1946) (Box 3.3.2).

Chukchi Sea and northern Bering Sea

Historical benthos sampling
Most systematic benthic sampling in the northern Bering and Chukchi Seas dates back to the early 1970 to 1990s, with published records for both epi- and macrofauna (e.g., Feder et al. 2005, 2007, respectively). Examples of some of the larger research endeavors include the Joint U.S.-USSR Central Pacific Expedition (BERPAC), St. Lawrence Island Polynya Project in the northern Bering Sea (SLIPP), and the Outer Continental Shelf Environmental Assessment Program (OCSEAP). A total of 1,406 macrozoobenthos species/taxa have been recorded in the Chukchi Sea, with the most diverse groups being arthropods, mollusks, polychaetes and bryozoans (Box 3.3.1).

Current benthic megafaunal monitoring by trawl
In the U.S., regions of commercial fisheries in the southern Bering Sea are monitored through annual trawl surveys, which routinely also record benthic invertebrate bycatch in addition to fish (NOAA RACE database). Commercial trawling activities may be a cause of reduced biodiversity found in fished compared with unfished regions of the Bering Sea (McConnaughey et al. 2000). With a decline in sea-ice cover and the potential of increased regular ship traffic in the high Arctic, the possibility of a fisheries development in the Chukchi and Beaufort Seas is increasingly possible. In response, an Arctic Fisheries Management Plan has been formulated, which sets a baseline for sustainable harvests, but currently does not permit commercial fisheries (NPFMC 2009) and no annual surveys are currently being conducted. Future annual groundfish surveys could be expanded into the Arctic Chukchi and potentially Beaufort Seas. Current benthic assessments in the Chukchi Sea are being done through individual research projects (e.g., Chukchi Sea Offshore Monitoring in Drilling Area – Chemical and Benthos (COMIDA—CAB), Arctic Ecosystem Integrated Studies (Arctic EIS), and the Chukchi Sea Environmental Studies Program (CSESP), also see Grebmeier et al. 2015b). In some cases, such as the NOAA-funded Russian American Long-Term Census of the Arctic (RUSALCA) program or the Distributed Biological Observatory (DBO), research plans include repeated benthic sampling at the same stations over time. The recently installed Arctic Marine Biodiversity Observing Network (AMBON) aims to identify sampling schemes that could provide the basis for a long-term biodiversity monitoring program in the Arctic. More than 300 megabenthic species/taxa are regularly identified during each these research programs (e.g., Bluhm et al. 2009, Blanchard et al. 2013, Ravelo et al. 2014), providing a solid baseline of megabenthic species/taxon occurrences in the Chukchi Sea region (Box 3.3.2) despite the lack of fisheries-based monitoring surveys.

Beaufort Sea

Historical benthos sampling
One of the earliest documented benthic grab and trawl investigations on the U.S. (western) side of the Beaufort Shelf was the Western Beaufort Sea Ecological Cruise (WEBSEC) study in the early 1970s, reporting the occurrence of > 100 polychaete species/taxa and ~150 gammarid amphipod species alone (Carey 1976). Subsequent U.S. Beaufort explorations focused mostly on fishes, but also yielded information on benthic invertebrates (Frost and Lowry 1983), or on the nearshore lagoon systems. The Canadian Arctic Expedition, 1913 to 1918, was the first scientific expedition to provide a comprehensive collection of marine benthos from the Canadian (eastern) Beaufort Sea. Interest in this region was revived nearly 50 years later when hydrocarbon exploration spurred ambitious field programs (e.g., Wacasey 1975, Wacasey et al. 1977, Atkinson and Wacasey 1989a). With improved logistic capabilities, widespread field programs including macro- and megabenthic community assessments flourished in the last decade in projects such as the Canadian Arctic Shelf Exchange Study (CASES), the Northern Coastal Marine Studies (CCGS *Nahidik* program), the International Polar Year-Circumpolar Flaw Lead System Study (IPY-CFL), the Beaufort Regional Environmental Assessment (BREA), and research collaborations among the CCGS *Amundsen* program, ArcticNet, Canadian Healthy Ocean Network (CHONe), and various oil companies. By gathering historical and recent data from all different types of gear, a total of 1,047 epi-, in- and hyperfauna species/taxa have been recorded. In decreasing order, arthropods, polychaetes and mollusks were the most species/taxon-rich groups (Box 3.3.1).

Current benthic megafauna monitoring by trawl
Recent investigations commenced in 2008, when a trawl survey using the same methods as the annual groundfish surveys in the Bering Sea were conducted in the western U.S. Beaufort Sea, identifying 174 benthic invertebrate species (Rand and Logerwell 2011). Other investigations between 2011 and 2014 through the U.S. Bureau of Ocean Energy Management (BeauFISH and U.S.-Canada Transboundary projects) supported shelf and slope investigations including epibenthic trawls. Across the U.S. Beaufort Shelf, 133 epibenthic species/taxa from 71 trawls were identified (Ravelo et al. 2015), while up to 160 epibenthic species along the central Beaufort Sea shelf and slope were recorded (K. Iken, B.A. Bluhm, unpubl. data). Recent investigations in the Canadian Beaufort Sea started around 2007 at the onset of the IPY-CFL scientific program and continued mostly thereafter under the CCGS *Amundsen* program. The BREA scientific program carried out extensive fish surveys from 2012 to 2014, yielding a vast amount of data on benthos in bycatch (Majewski et al. 2016). There is, however, no recurring annual bottom trawl survey in the either part of the Beaufort Sea. For the entire Beaufort Sea region, total richness ranged from 1 to 119 megafaunal species/taxa per haul (Box 3.3.2).

Canadian Arctic Archipelago, Hudson Bay Complex, western Davis Strait-Baffin Bay

Historical benthos sampling
Few historic research-based studies have been carried out in the Canadian Arctic Archipelago (e.g., Thomson 1982, Atkinson and Wacasey 1989a), the Hudson Bay Complex (e.g., Wacasey et al. 1976, Atkinson and Wacasey 1989b) and the western Davis Strait-Baffin Bay region (e.g., MacLaren 1978), and if so, they were mostly based on grab sampling. Over the last decade, many research projects (Link et al. 2013a, Goldsmit et al. 2014, Roy et al. 2015) and programs (e.g., CCGS *Amundsen*, ArcticNet, CAISN II, CHONe) investigated benthos

in parts of these regions. By gathering available historic and recent data from all research-based inventories, which used different types of gear, a total of 1,151 epi-, in- and hyperfauna species/taxa have been recorded in the Canadian Arctic Archipelago, 841 species/taxa in the western Davis Strait-Baffin Bay region and 786 species/taxa in the Hudson Bay Complex. In decreasing order, arthropods, polychaetes and mollusks were the most species/taxon-rich groups in all three regions (Box 3.3.1).

Current benthic megafauna monitoring by trawl

For the Canadian Arctic Archipelago and northern Davis Strait-Baffin Bay regions, the studies of Roy et al. (2014, 2015) represent the most recent research-based investigations on megabenthic communities. The Davis Strait-Baffin Bay region and the Hudson Bay Complex are the only two Canadian Arctic regions where commercial fisheries occur. Fisheries and Oceans Canada (DFO) has been conducting an annual multi-species depth-stratified bottom trawl survey to perform stock assessments of Greenland halibut (*Reinhardtius hippoglossoides*) and northern and striped shrimps (*Pandalus borealis* and *P. montagui*, respectively) since 1999, but it is also used for biodiversity monitoring (K. Hedges, pers. comm.). All bycatch invertebrate groups are identified, but there are not yet thorough and systematic surveys of benthic communities at species level (Siferd 2015). Across the three regions, estimates of total richness from research-based investigations at a total of 281 stations ranged from 1 to 119 species/taxa per station. In the Davis Strait-Baffin Bay and Hudson Bay Complex regions, estimates of total community richness from bottom trawl bycatch surveys, including a total of 3,477 stations, ranged from 3 to 59 species/taxa per station. Considering all types of trawl, most of the high-to-intermediate richness stations were distributed across the Canadian Arctic Archipelago, in the northern and southern areas of the Davis Strait-Baffin Bay region and the Hudson Strait, while low-to-intermediate richness stations occurred mostly in nearshore areas of Hudson Bay and along the northern end of the Baffin Island shelf (Box 3.3.2).

Arctic Basin

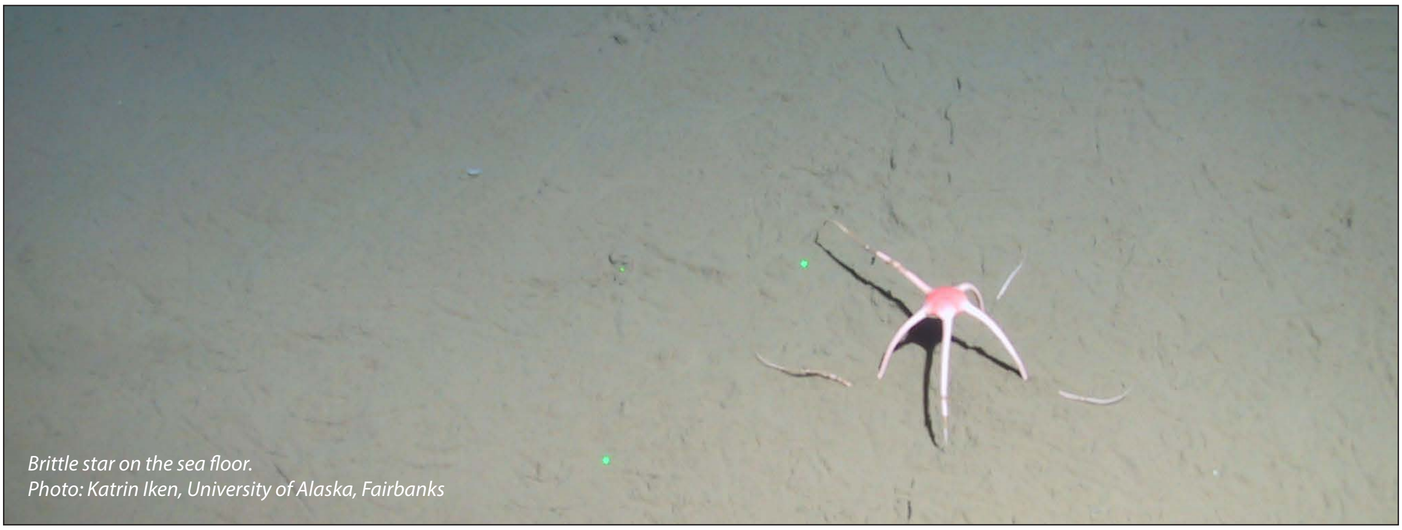
Historical benthos sampling

A number of early efforts such as the Norwegian *Nordhavs* expedition in 1876-1878 (Danielson 1890) and the Russian *Sedov* expedition in 1937-1940 (Gorbunov 1946, Gurjanova 1946), facilitated a first synthesis in which Sirenko (2001) summarized 712 taxa for the 'Arctic Basin' (although with undefined depth cut-off). More recent research efforts conducted between the late 1990s and 2010 increased the inventory to 1,125 benthic taxa found at stations deeper than 500 m and northwards of 80°N in Fram Strait (Bluhm et al. 2011). The macrobenthic species/taxon richness is dominated by arthropods and annelids, and within the meiofauna by foraminiferans and nematodes (Box 3.3.1). Also of note is that macrofauna decrease in body size with increased depth, and this happens more so than with meiofauna (Rex et al. 2006, Wei et al. 2010).

Within arthropods, amphipods are richest in species, followed by isopods and harpacticoid copepods. For few species, more than 20 records exist and about half of all taxa have been reported from only one or two stations.

Current benthic megafauna monitoring by trawl

Most benthic research efforts in the deep-sea Arctic Basin have focused on macrofauna (syntheses by Bluhm et al. 2011 and Mironov et al. 2013) and meiofauna (syntheses by Vanreusel et al. 2000, Soltwedel et al. 2009). Megabenthic communities have been studied by only few trawl catches or by photographic surveys mostly along slopes (Soltwedel et al. 2009, MacDonald et al. 2010), with recent efforts focused on the Beaufort Sea slope to ~1000 m (Norcross et al. 2015, Majewski et al. 2016). No regular benthic sampling is being conducted in the Arctic Basin by any nation. Specific monitoring locations in the Arctic Basin have not yet been identified, because of the sparse previous sampling. Locations, however, should be determined such that they would capture potentially changing benthic communities along the Arctic Circumpolar Boundary Current and Atlantic Deep Water inflow through Fram Strait, and into the American Basin (Fig. 3.3.1). This could be a curved transect crossing the Arctic Basin from west of Svalbard to the Bering Strait. When this transect is crossed by a research vessel the data could be added into the database of the Distributed Biological Observatory (DBO).



Brittle star on the sea floor.
Photo: Katrin Iken, University of Alaska, Fairbanks

3.3.3 Status and trends of FECs

Despite extensive benthic research in various regions of the Arctic, there are only few that have been systematically sampled over sufficiently long time periods to allow a reliable assessment of potential changes in benthos. In the following, the CBMP Benthos Expert Network presents three examples of documented scientific long-term studies evaluating changes in benthic community structure and biomass on annual to decadal scales.

Case study 1: Recent trends – Multiple impacts on Barents Sea megabenthos (2007-2015)

The Barents Sea trawl investigations (see above) found high megabenthic biomass in the cold waters along the southern and western coast of Novaja Zemlya (sponges, sea urchins, snow crabs, and crangonid shrimps), on the Spitsbergen Bank influenced by Atlantic water (sea cucumbers, Iceland scallop (*Chlamys islandica*), sponges, lyre crabs, and sea stars), and in the southwestern Barents Sea (sponge field) (Fig. 3.3.2). The south-central Barents Sea was characterized by lowest megabenthic biomass. A general decrease in biomass over the recent decade has been observed in the central Barents Sea, with a minimum in 2015. Whether the biomass reductions are due to rapid climate change, such as ocean warming, or rather to other natural (e.g., predation from snow crabs or benthivorous fishes) or human pressures (e.g., trawling) have not yet been fully identified. In 2007, megabenthic biomass increased northwest of Kap Kanin (Fig. 3.3.2) due to the invasion of the introduced king crab (*Paralithodes camtschaticus*) (Orlov and Ivanov 1978). This species has now spread to coastal areas in the Russian and Norwegian parts of the Barents Sea. Similarly, an increase in megabenthic biomass in the northeastern Barents Sea in 2011 has at least in part been attributed to an increasing population of the invasive snow crab (Fig. 3.3.2). As it is a coldwater species living at water depths from 20 to 700 m and temperatures below 5 to 8°C (Elner and Beninger 1992), it is expected to spread over most of the Barents Sea (Renaud et al. 2015). Pavlov and Bakanev (2012) consider the snow crab (*Chionoecetes opilio*) invasion as one of the most significant threats currently to biological diversity in the region. In addition, the recent warming in the Barents Sea is expected to lead to a borealization of megabenthic communities, similar to what has been observed for fish communities (Fossheim et al. 2015). The benthic communities of the southwestern and coastal areas of the Barents Sea are consistently boreal in terms of their biogeographic composition, i.e., they lack truly Arctic species, but it is recognized that the warming of the Barents Sea is pushing boreal species farther north. Northward migrating commercial fish stocks have already initiated new commercial trawling activity in the northern Barents Sea. This makes the area east of Svalbard a possibly vulnerable area subjected to multiple impact factors, including ocean warming, bottom trawling, and invasions of non-indigenous species, such as the snow crab.

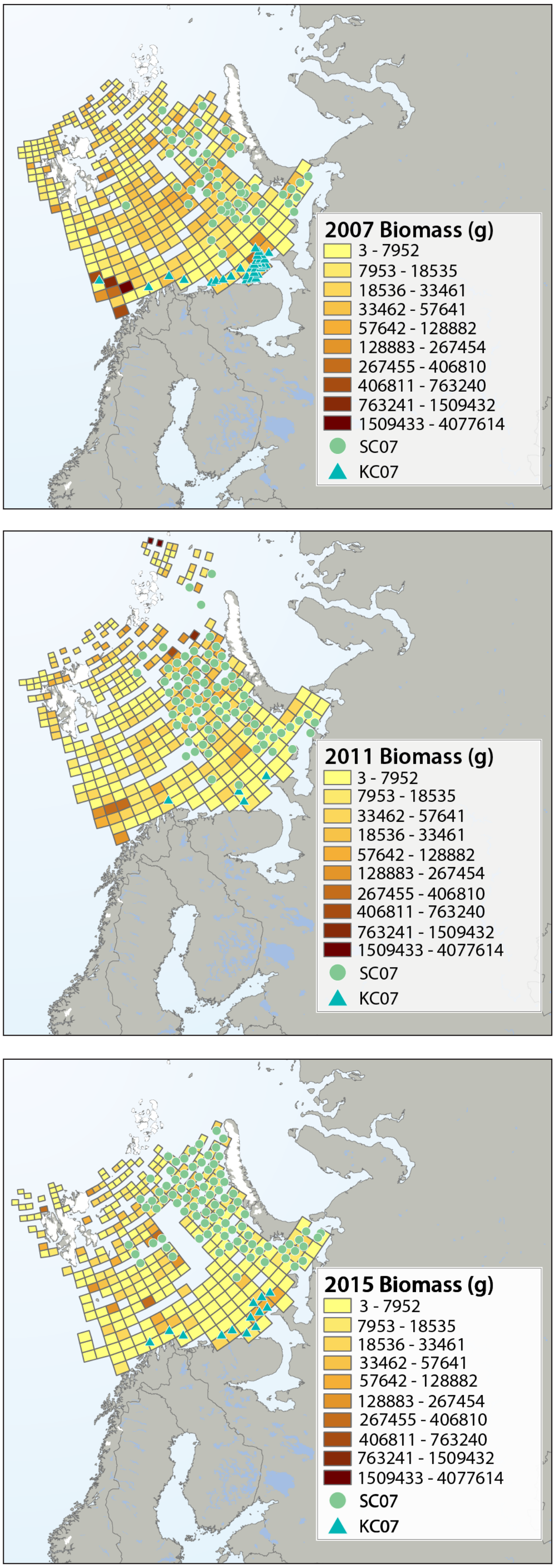


Figure 3.3.2: Megafauna distribution of biomass (g/15 min trawling) in the Barents Sea in 2007, 2011 and 2015. The green circles show the distribution of the snow crab as it spreads from east to west, and the blue triangles show the invasion of king crab along the coast of the southern Barents Sea. Data from Institute of Marine Research, Norway and the Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia.

Case study 2: Decadal trends – Barents Sea macrobenthic biomass fluctuations (1924-2003)

The distribution of macrobenthic biomass in the Barents Sea varied between 1924 and 2003 (Fig. 3.3.3). The average biomass values for the entire study region declined about 2.5-fold between the 1930s and the 1960s (from 147.0±11.7 to 59.5±4.3 wet weight g m^{-2}) (Denisenko 2001). In 2003, however, average biomass even exceeded the high values from the 1930s (Denisenko 2013). Despite the general dynamics in the distribution of macrobenthic biomass, some biomass hotspots persisted over time, especially south of Svalbard and within the central focus area (blue box in Fig. 3.3.3). It has been suggested that some of the biomass decline between the 1930s and 1960s was the result of bottom trawling (Denisenko and Denisenko 1991), whereas the increase observed between the 1960s and 2003 (within the focus area inside the blue box in Fig. 3.3.3) could be caused by climate change.

In the early 1990s, negative impacts of commercial fish trawling on the macrozoobenthos biomass in the Barents Sea were quantified (Fig. 3.3.4) (Denisenko and Denisenko 1991). A strong four-year lag relationship existed between total macrobenthos biomass and bottom trawl intensity (Fig. 3.3.5) (Denisenko 2001). Degradation of benthic communities was also detected in the 2000s, indicating the continuing impact of increased trawling activities in the region (Manushin et al. 2008).

About 30-50% of known cold water coral reefs along the northern coast of Norway have been damaged most likely due to bottom trawling in the Barents Sea (Fosså et al 2002) and biomass of sponges has decreased 20-fold in the southwestern part of the sea (Denisenko 2013). Strong damage was also observed in bottom communities as result of unsustainable exploitation of target species, such as the Iceland scallop (Denisenko 2013). Large concentrations of this megabenthic species were discovered in the Barents Sea in the late 1980s (Denisenko and Bliznichenko 1989) and commercially exploited during the following 20 years. These populations have now been completely depleted on Goose Bank, and the Svyatonosskaya population near the Kola Peninsula has been seriously reduced (Bakanev and Zolotarev 2012).

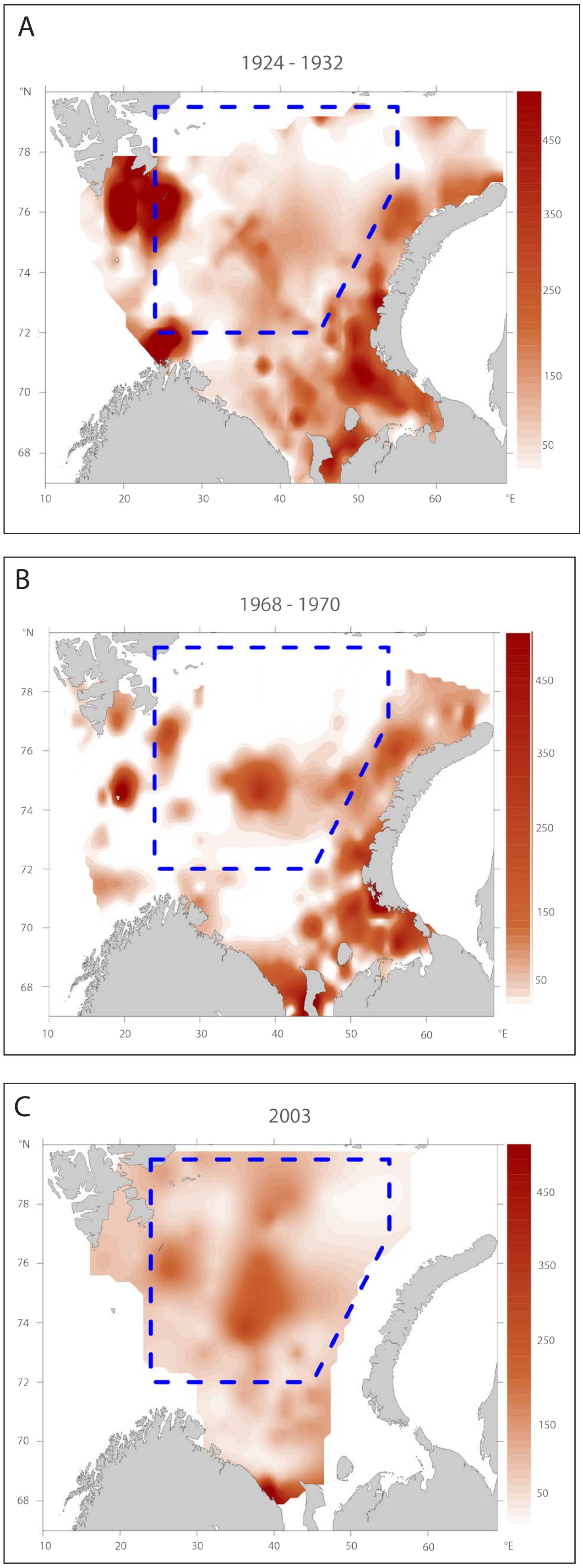


Figure 3.3.3: Macrofauna distribution of biomass (g wet fixed weight m^{-2}) in the Barents Sea over three time periods: 1924-32 (Figure A), 1968-70 (Figure B) and 2003 (Figure C, constructed from original archive data, except for area south of 72° N where digitized megafaunal-data taken from Anisimova et al. (2010) was used. Adapted from Denisenko (2013). Blue boxes delineate the areas within which the zoobenthos biomass values were compared.

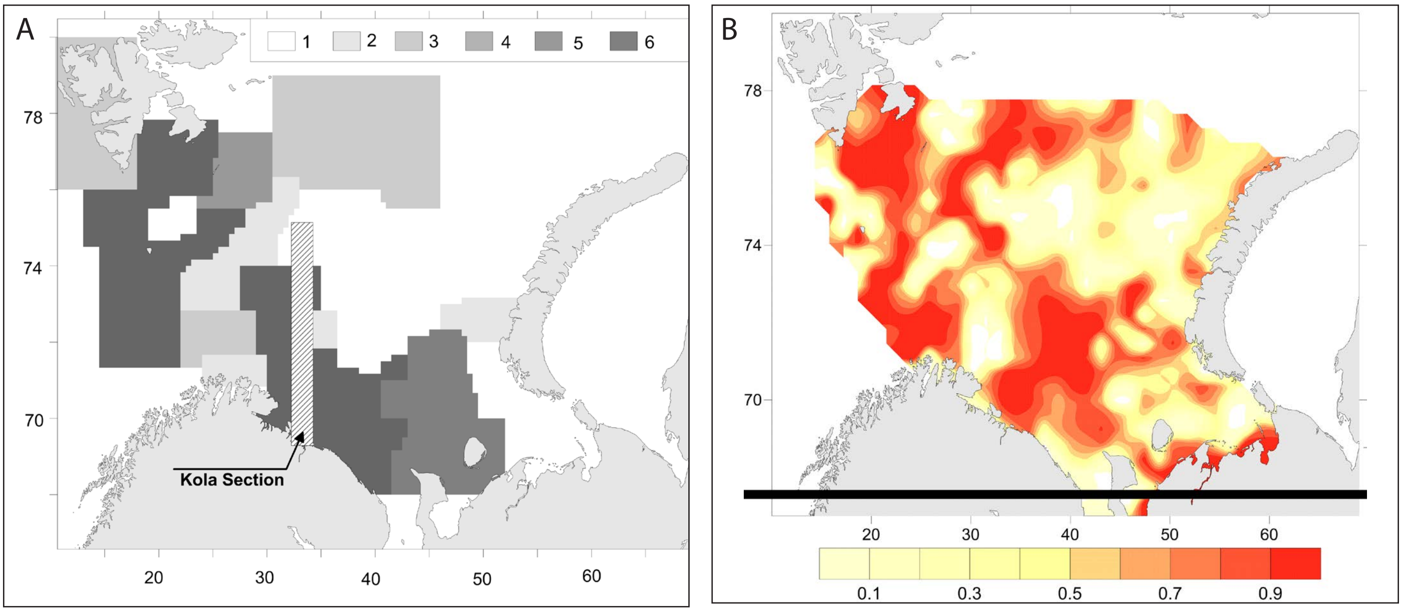


Figure 3.3.4: Commercial fishery impact on zoobenthos of the Barents Sea. Figure A) Intensity and duration of fishery efforts in standard commercial fishery areas in the Barents Sea. The darker the area the longer the fishery has been in operation. Figure B) Level of decline in macrobenthic biomass between 1926-1932 and 1968-1970 calculated as 1-b1968/b1930. The largest biomass decreases correspond to the darker colour, whereas lighter colour refers to no change (Denisenko 2013).

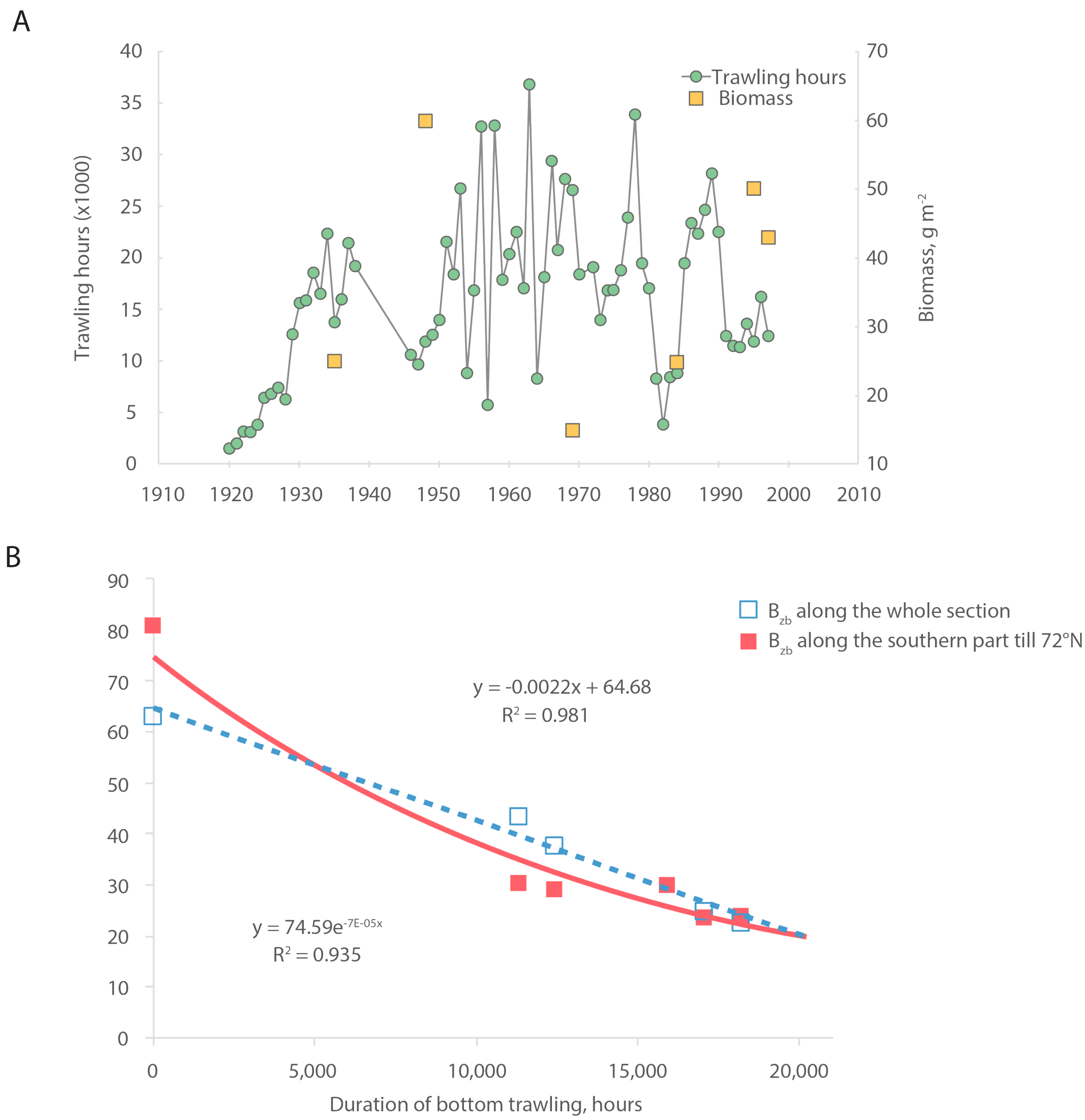


Figure 3.3.5: Variation of average annual trawling activity (in hours) and macrobenthic biomass (g m^{-2}), (a) and relationship of biomass with a four-year lag (mean value of time of the turnover in biomass value) to trawling activity, (b) along the Kola section of the Barents Sea during 1920-1997 (Denisenko 2001, 2013).

Case study 3: Decadal trends, Pacific Arctic – Northern Bering Sea and Chukchi Sea macrobenthic biomass distribution (1970-2000s)

Biomass distribution of infaunal macrobenthos in the Chukchi Sea was considered in the analysis of decadal patterns from the 1970s to the 2000s (Fig. 3.3.6). Several benthic biomass hotspots persisted over the decadal sampling. A biomass hotspot in the Chirikov Basin, just south of Bering Strait, has noticeably diminished in biomass since the 1970s. This is a traditional feeding area for gray whales, foraging on ampeliscid amphipods, but gray whales have declined in that region since the 1980s (Moore et al. 2003). The shift in gray whale foraging away from the Chirikov Basin is likely driven by a decline in their amphipod prey, perhaps in part from overexploitation from gray whale feeding but possibly also from climate-initiated ecosystem changes including shifts in currents causing changes in sediment grain size (Coyle et al. 2007, Grebmeier 2012). Another hotspot, in the south-central Chukchi Sea, has persisted over the study period since the 1980s, although a biomass reduction has become noticeable in the most recent decade (Grebmeier et al. 2015a). This hotspot is sustained by the slowing of fast-flowing water entering through the narrow Bering Strait, which causes an increase in settlement of nutrient-rich particles to the benthos (Grebmeier 2012). The benthos in this area is dominated by bivalves (Grebmeier et al. 2015a), which are important food for many benthic feeding marine mammals (e.g., walrus; Jay et al. 2012, Moore et al. 2014). The recent benthic macrofauna biomass declines in this region could be due to changes in flow dynamics through Bering Strait, changes in benthic habitat features such as sediment grain size, and possibly foraging pressures (e.g., Moore et al. 2003).

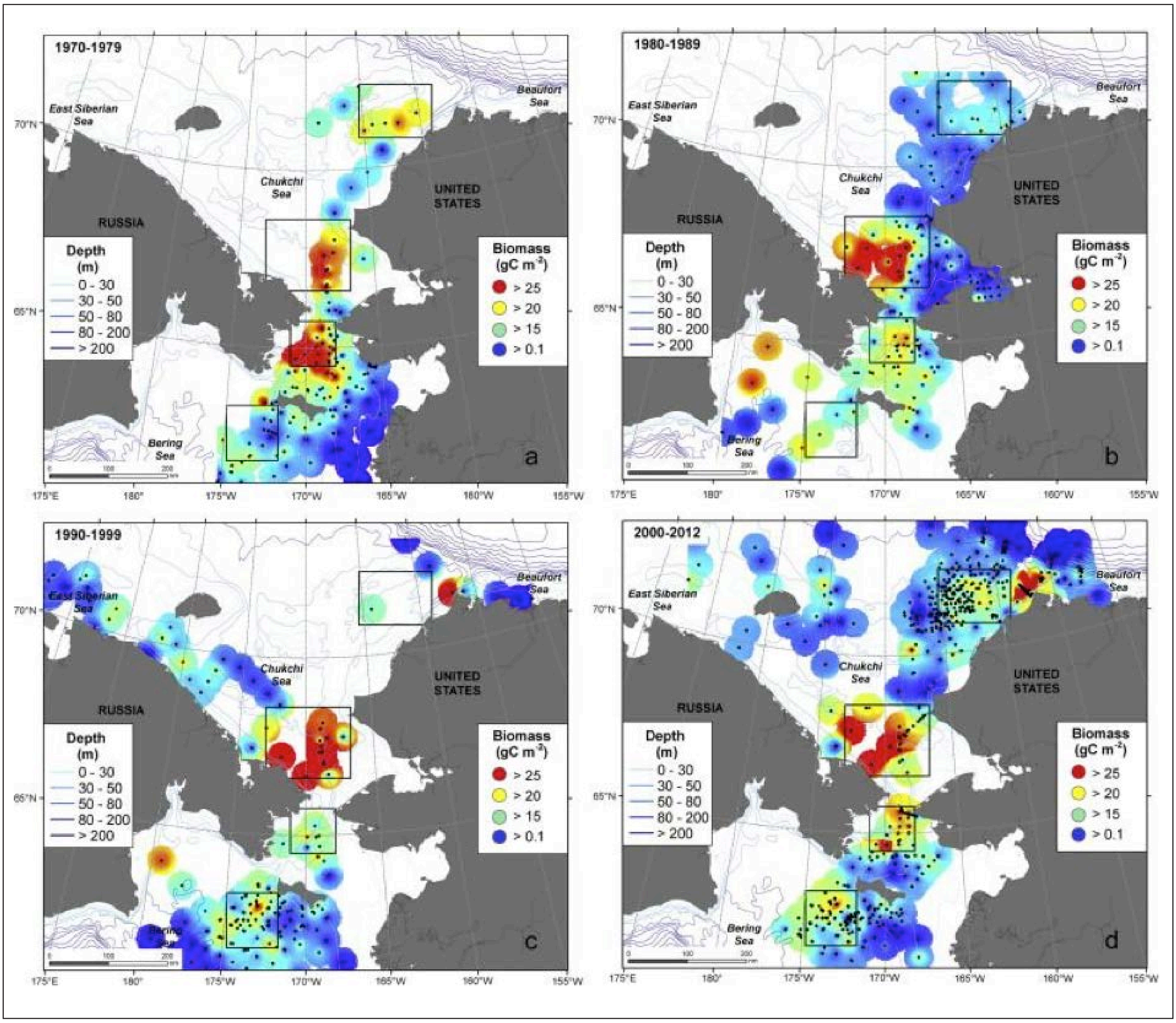


Figure 3.3.6: Benthic macro-infauna biomass in the northern Bering and Chukchi Seas from 1970 to 2012, displayed as decadal pattern Adapted from Grebmeier et al. (2015a) with permission from Elsevier.

Box 3.3.3 Indigenous Knowledge of benthic species

Vera Metcalf, Eskimo Walrus Commission, Inuit Circumpolar Council Alaska and Carolina Behe, Inuit Circumpolar Council-Alaska

There is a wealth of Indigenous Knowledge (IK) on benthic species within Inuit communities. This IK is an invaluable knowledge resource, reaching back thousands of years, to aid in the understanding of changes occurring within the Arctic.

Along Arctic coasts, benthic animals wash up regularly on shorelines mostly during autumn after a storm. Many of us enjoy these resources for food. After a storm, we often search along the beaches and collect the 'seafood'. Over time, we are able to see and recognize when and where there are changes in the distribution and quantity of these resources.

Our knowledge teaches the importance of understanding interconnections within the Arctic to determine how some of these changes may be occurring. For example, sea ice coverage, thickness, sand bar location, and ocean currents all play a role in the health of life in the Arctic, including benthic resource species.

Benthic species are also an important food source for walrus. Many of us rely on walrus and consider it a very important natural resource in our culture. When we hunt, harvest, and process walrus, we enjoy the benthic species found in the stomach. Over time, we observed a decreasing volume of benthic prey, particularly clams, and an increasing volume of pelagic fishes, or simply sand, in walrus stomachs.

The change in walrus stomach contents indicates that the distribution and availability of benthic resource species are changing in some areas. This information validates some Elders who have noted that this change is linked to a decrease in sea-ice coverage, dislocations of sand bars, and alterations of water currents.

Marine food sources for people around the Bering Sea include Ascidians (possibly *Boltenia ovifera* on stalk and other colonial ascidian species).


Photos: Carolina Behe

3.3.4 Drivers of observed trends

Benthic fauna are generally sensitive to variations in the surrounding environment and can respond at different ecological levels (species, populations, and ecosystems). Effects of climate change on benthic populations are complex and are mainly related to changes in bottom-water temperature, sea-ice dynamics, coastal erosion, freshwater and sediment inputs from rivers, melting glaciers and permafrost, and in the ocean carbon budget (ocean acidification) (Piepenburg 2005). Commercial bottom trawling is an anthropogenic driver that has been demonstrated to cause fluctuations in benthic biomass (Denisenko 2013). The impacts of such environmental and anthropogenic drivers may weaken existing community interactions and facilitate the invasion of non-indigenous species into Arctic regions (Renaud et al. 2015). Records of impacts from potential drivers of change vary among Arctic regions. Here, the CBMP Benthos Expert Network provides their first assessment of the importance of six major drivers of change, along with their cumulative impact for different Arctic regions (Table 3.3.1). No attempt has been made, however, to weigh or prioritize these drivers because of the lack of quantitative information in many regions.

Sea ice extent and thickness influence benthic communities mostly indirectly through effects on hydrographic conditions and primary production (Link et al. 2011). Thus, changes in sea-ice dynamics will alter benthic energy flow with subsequent effects on standing stock, community interactions and, hence, ultimately also biodiversity. In the Barents Sea, there is also evidence of warming bottom temperatures (Jørgensen et al. 2015), a second driver expected with climate change. Higher ambient temperatures modify the environmental conditions experienced by benthic organisms, exceeding the temperature limits of some stenothermal (e.g., Arctic) species but opening these regions to taxa that require warmer conditions for growth and reproduction (e.g., boreal species). This factor is especially expected in inflow regions of the North Atlantic and North Pacific (Table 3.3.1).

As many large river systems and heavily glaciated areas around Greenland and the Eastern Arctic Archipelago drain into the Arctic Ocean, freshwater influence from increased melting and discharge of these sources is expected to be a strong driver in these Arctic regions. Reduced ***salinity*** will directly affect the osmotic balance of benthic species and may also cause indirect effects through changes in stratification patterns and associated primary productivity regimes. Witman et al. (2008) showed a significant effect of chlorophyll *a*, which co-varied with the salinity in the Canadian Arctic, on benthic biodiversity suggesting that environmental stress as well as productivity influence diversity in these marine systems.

The potential impacts of ***ocean acidification*** on benthic biodiversity are not well known. Although several regions have been identified to experience reduced alkalinity, such as the Chukchi and Beaufort Seas, the exact biological sensitivities are still to be determined. However, it is well known that many non-Arctic calcareous species have reduced shell-building capacity and metabolic and behavioral effects. Ocean acidification will likely impact Arctic benthic species in both their adult benthic and/or pelagic larval stages, and juvenile stages are generally found to be the most sensitive.

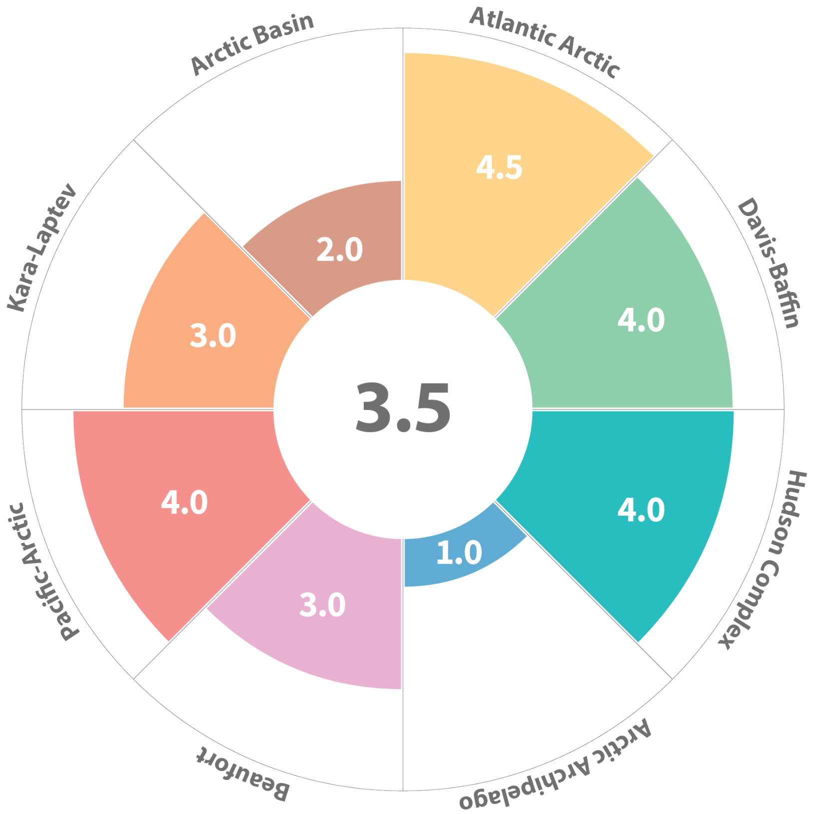


Figure 3.3.7: Cumulative scores of various environmental and anthropogenic drivers of change of the benthic ecosystem across the eight Arctic Marine Areas (AMA). A cumulative score is the median score of sub-regions per AMA (Table 3.3.1). Median score for the whole Arctic is given in the centre.

Table 3.3.1. Presence or absence (1/0) of various environmental and anthropogenic drivers of change of the benthic ecosystem across the different Arctic sub-regions. Median score of sub-regions per Arctic region is given in bold. A cumulative score of 1-2 is considered low, 3-4 intermediate, 5-6 high, and a score of na indicates a lack of information. NIS indicates non-indigenous species.

Arctic Region / Sub-Region	Sea-ice Dynamics	River or Glacier Influence	Bottom Water Temperature Change	Ocean Acidification	Commercial Bottom Trawling	Risk of Introduction of NIS	Cumulative Score
Atlantic Arctic	**0**	**1**	**1**	**0.5**	**1**	**1**	**4.5**
Greenland (northeast)	1	1	na	na	0	na	2
Greenland (southeast)	1	1	na	na	1	na	3
Iceland (north)	0	1	1	1	1	na	4
Iceland (south)	0	1	1	0	1	na	3
Faroe Islands (shallow)	0	0	1	na	1	1	3
Faroe Islands (deep)	0	0	0	na	1	1	2
Norwegian Shelf (northwest)	0	0	1	na	1	na	2
Barents Sea (northwest)	1	1	1	na	1	1	5
Barents Sea (southwest)	0	0	1	na	1	1	3
Barents Sea (northeast)	1	0	1	na	0	1	3
Barents Sea (southeast)	1	1	1	na	1	1	5
Kara-Laptev	**1**	**1**	**1**	**na**	**0**	**na**	**3**
Kara Sea	1	1	1	na	0	na	3
Laptev Sea	1	1	na	na	0	na	2
Pacific Arctic	**1**	**0**	**1**	**1**	**0**	**1**	**4**
East Siberian Sea	1	0	1	na	0	na	2
Chukchi Sea (Russia)	1	0	1	na	0	1	3
Chukchi Sea (USA)	1	0	1	1	0	1	4
Northern Bering Sea	1	1	1	1	1	1	6
Beaufort Sea	**1**	**1**	**na**	**1**	**0**	**na**	**3**
Beaufort Sea (USA)	1	1	na	1	0	na	3
Beaufort Sea (Canada)	1	1	na	na	0	na	2
Arctic Archipelago	**1**	**0**	**na**	**na**	**0**	**0**	**1**
Hudson Bay Complex	**1**	**1**	**na**	**na**	**1**	**1**	**4**
Davis Strait-Baffin Bay	**1**	**1**	**na**	**na**	**1**	**1**	**4**
Canada (west)	1	1	na	na	1	1	4
Greenland (northwest)	1	1	na	na	1	na	3
Greenland (southwest)	0	1	na	na	1	na	2
Arctic Basin	**1**	**0**	**1**	**na**	**0**	**na**	**2**

Trawling impacts on certain benthic communities are particularly strong in regions with regular commercial trawling activities, such as in the Barents Sea (Denisenko 2001) and other Atlantic Arctic regions, also in the Davis Strait-Baffin Bay Complex (Yesson et al. 2016). The constant disturbance erodes the resilience of these vulnerable bottom communities, and only few opportunistic species are able to survive. This may be exacerbated in cases where trawling targets specific species and, thus, further alters the overall community dynamics. Trawling in areas recently covered by sea-ice most of the year are very vulnerable due to large upraised species easily taken by a trawl-gear (Jørgensen et al. 2016).

Changes in environmental conditions (e.g., warmer inflowing currents) and vessel-related activities (e.g., ballast waters; see also Chapter 4) open opportunities for ***non-indigenous species*** to enter the Arctic systems. These non-indigenous invaders can have the potential to outcompete highly adapted, native species and cause major interruptions of existing communities. Some specific examples of invasive species with impacts on bottom communities are already known, for example king crabs (Britayev et al. 2010) in the Barents Sea region, and the possible impact from snow crabs are being evaluated from the same area.

3.3.5 Knowledge and monitoring gaps

As outlined above, a considerable amount of information about Arctic benthic communities has been collected over the past century. However, the lack of consistency and methodological standardization in combination with limited geographic coverage limits our ability to assess large-scale (from regional to pan-Arctic) and long-term dynamics in benthic communities, which is urgently needed to assess effects of anthropogenic activities and a changing environment.

A truly large-scale, long-term and internationally comparable monitoring of benthic faunal assemblages does not exist for the entire Arctic. The main reason for this is most likely the significant costs of running such monitoring programs, and the challenges to develop international standards. Therefore, there is a need to formulate some standards for benthos monitoring in the Arctic that 1) are realistic given the logistical, scientific and economic constraints existing in all Arctic countries, 2) will ensure a description of key components in benthic faunal communities, and 3) have the potential to document large-scale and long-term trends in the dynamics of selected benthic indicators with regard to drivers related to climate change, trawling impact, pollution and other potential anthropogenic and natural drivers. This has led to the suggestion of focusing on megabenthic invertebrate fauna caught by bottom trawls as being the most practical environmental indicator organisms for countries that have regular surveys in place (Blicher et al. 2015, Jørgensen et al. 2015). This monitoring can be implemented either as part of already existing long-term national, annual groundfish/shellfish assessment surveys, or alternatively, as part of shorter-term research projects.

For those areas where annual groundfish-shellfish assessment surveys take place, an expansion of the Long-Term Monitoring for Benthic Megafauna program, described in Chapter 3.3.1 and implemented in the Barents Sea by Norway and Russia, and recently off Greenland, may serve as a model to design a broader international monitoring program. The CBMP Benthos Expert Network suggests to establish a pan-Arctic scientific expert exchange program to stimulate a process of knowledge sharing and the implementation of a standardized approach to sampling, species identification, as well as data entry and storage. This approach to monitoring is cost-effective because it capitalizes on existing logistic platforms. In addition, it has already proven to be effective for documenting large-scale patterns in the distribution of benthic megafauna (Moritz et al. 2013, Jørgensen et al. 2015, 2016, Degen et al. 2016) and enables the initial detection of potential vulnerable habitats, valuable ecosystem components, or areas subject to change (e.g., hotspots of biodiversity and/or production, invasive species, feeding grounds for mammals). This approach can, therefore, assemble the groundwork to assess long-term changes and potential drivers of these changes.

For the vast areas of the Arctic without annual groundfish-shellfish assessment surveys, collection of benthic information will have to rely on intermittent research projects. Such project-based surveys will be less regular and will not sample the same regions repeatedly, but can eventually also produce comparable data to monitored regions, if standardized protocols are followed. It is advised that trawl sampling be applied for greatest comparability among Arctic regions and because it is relatively cost-effective. Great care should be taken to ensure consistent operating procedures, including the type and use of sampling gear, species identification, sample processing, data entry and storage. It is clear, however, that long-term assessments based on research projects are subject to changes in national research strategies and, hence, will very likely not produce time-series data with the same reliability as regular groundfish-shellfish assessment surveys.

While the focus here has been on megabenthic monitoring based on trawl surveys because of the existing infrastructure in several Arctic countries, macrofaunal collections are equally important. Macrofauna serve as important prey for upper trophic benthivores on shallow Arctic continental shelves and are valuable long-term integrators of overlying water column properties because they have generally little mobility. Also, macrofauna sampling leaves a much smaller footprint on the seafloor than trawling. Therefore, a strong biodiversity program would include multiple scales of benthic faunal sampling, including macro-infauna.

Seastar. Photo: NOAA

Laetmonice filicornis.
Photo: Olga Zimina, Greenland Institute of Natural Resources

3.3.6 Conclusions and key findings

Status of Knowledge on Biodiversity

- Knowledge of benthic fauna diversity in all regions based on historical and current studies has accumulated > 4,000 known Arctic macro- and megabenthic species. This number does not include what we expect to be a considerable number of micro- and meiofaunal species, which are often not part of regular sampling programs with bottom trawls or traditional grab-sampling projects.
- Across all regions, the highest macro- and megabenthic taxonomic richness is within arthropod, mollusk and polychaete groups.
- There is a great need of information about little-known regions, such as the deep-sea Arctic basins, the high Canadian Arctic Archipelago, cryptic or difficult-to-identify taxon groups, and biological hotspots.

Temporal Trends and Drivers

- In the Barents Sea, macro- and megabenthic biomass declines are attributed to trawling impacts, while biomass increases are linked to the spreading of non-indigenous boreal (e.g., red king crab) or more sub-Arctic (e.g., snow crab) species.
- Sea-ice dynamics, ocean mixing, bottom-water temperature change, commercial bottom trawling, ocean acidification, river/glacier freshwater discharge and introduction of non-indigenous species are regarded as major drivers of observed and expected changes in benthic community structure in the Arctic.
- Benthic species are important food sources for indigenous people and marine mammals and seabirds. According to Traditional Knowledge (TK), stocks of benthic prey have decreased in walrus stomachs, particularly clams, while pelagic fishes have increased. The knowledge of the people living at the coasts of the Arctic Ocean must be recognized as an invaluable resource for our understanding of changes in Arctic benthic communities.
- Increasing numbers of species are moving into, or shifting, their distributions in Arctic waters. These species will outcompete, prey on or offer less nutritious value as prey for Arctic species.

Long-term Monitoring

- From the perspective of long-term monitoring, we suggest that the systematic study of macrobenthic (grab investigations) and megabenthic (trawl bycatch in regular fishery surveys including both annual studies, as in the Atlantic Arctic, and Davis Strait-Baffin Bay including those conducted by Fisheries and Oceans Canada and Greenland Institute of Natural Resources, and periodical studies as in the Northern Bering and Chukchi Seas) are the most suitable and practical approach for a pan-Arctic biodiversity assessment. Standardization of methodology, including taxonomic identification, across regions will assist in pan-Arctic comparability.
- A formalized monitoring plan (updated from Gill et al. 2011) can build on existing national, annual groundfish-shellfish trawl surveys, such as the ones implemented successfully in the Atlantic Arctic regions and Greenland Similar efforts should be implemented in other regions where trawl surveys are done regularly.
- In regions without regular groundfish-shellfish trawl surveys, information should be gathered from research programs, which are usually short-termed and do not guarantee spatial consistency in sampling, but still provide valuable information on benthic biodiversity and community patterns.

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